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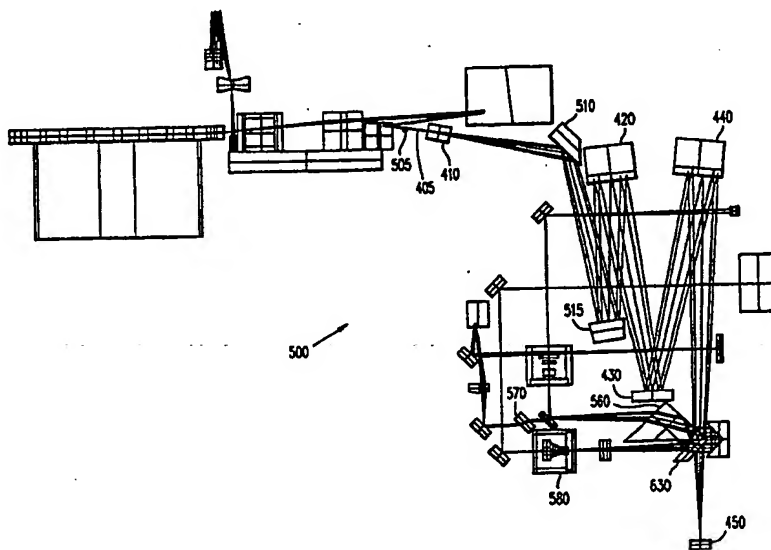
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(54) Title: HIGH EFFICIENCY LASER PATTERN GENERATOR



## (57) Abstract

A laser scanner includes an optical relay which reforms an image from a scan lens at a location that provides additional working distance. The optical relay contains primarily reflective elements which provide achromatic focusing for ultraviolet light. One embodiment of the optical relay has a magnifying power of about 1 and use spherical mirrors in a configuration where image distortion and aberrations cancels. A second optical relay provides a reduction in image size using aspherical mirrors such as parabolic and elliptical mirrors. An additional lens cancels distortion and aberration introduced in the second optical relay. The additional working distance allows insertion optical devices such as beamsplitters and chevron correction and autofocus optics in the optical path of the optical relay.

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## HIGH EFFICIENCY LASER PATTERN GENERATOR

5

CROSS REFERENCE TO RELATED APPLICATION

This patent application claims the benefit of the filing date of U.S. provisional application Ser. No. 60/052070, filed July 9, 1997.

10 BACKGROUND OF THE INVENTIONField of the Invention

This invention relates to laser scanning systems and laser pattern generators for precision laser direct imaging and mask making.

15 Description of Related Art

In photolithography, a raster scanning system is an optical device that scans one or more laser beams into a series of scan lines covering a photosensitive layer being patterned. A typical scanning system consists of one or more modulated lasers as sources of light beams, a mechanical or other device for scanning the beams through an angle, scan optics to convert the scanned beams into a set of scanned lines, and optics for matching the scanned lines to a desired image surface. Whether a raster scanner illuminates a specific region depends on the modulation of laser beam intensity as the beam scans past the region. A laser scanner's precision in selecting illuminated regions depends on the accuracy of modulation of the laser beam, the sharpness of the focus of the laser beam, the precision with which the laser beam moves across the layer being patterned, and synchronization between modulation and motion of the laser beam.

Laser direct imagers (LDIs) form a class of laser scanning systems that can replace reticle-based large area exposure devices. Typical LDI applications require exposure of ultraviolet sensitive photoresist, and require pixel sizes ranging from

25 to 2  $\mu\text{m}$  with pixel placement accuracy down to a tenth of a pixel. Scan optics for these precision imaging applications require that the optics concurrently provide diffraction-limited high resolution (low  $f/\#$  or small spot size), along the scan line distortion correction, an image field suitable for accommodating multiple scan lines, and telecentric imaging. Additionally, for ultraviolet direct imaging, the system should have good radiometric efficiency. This requires that the system transmission efficiency be high. The power transfer can additionally be increase if the system can use more than one of the available UV spectral lines from a laser.

An additional requirement of the scan optics in a scanner is adequate working distance from the last optical element to the media for clearance of material handling equipment and accommodation of auxiliary optical devices. Typical auxiliary optical devices include light sensors used in synchronizing scan beam motion with scan beam intensity modulation and correction optics which reshapes or move the image of the scan line to account for movement or indexing of the device being patterned.

Related art can be found within existing UV mask making technology for semiconductor microlithography, conventional laser scanners used for printed circuit board pattern generators and for graphic art applications. For example, U.S. Pat. Ser. No. 4,796,038 describes a known pattern generator for reticle making. However, several limitations of such systems can be noted. First, systems such as described in U.S. Pat. Ser. No. 4,796,038 make reticles which does not require ultrafast write times. With a laser direct imager, time to image a substrate is of paramount importance since imaging time directly affects manufacturing cycle times. Thus, the LDI systems require high radiometric efficiency not provided in systems for making reticles. Critical system distinctions that demonstrate improvements to known systems are described below.

#### SUMMARY OF THE INVENTION

In accordance with the invention, a laser direct imaging system includes a continuous wave laser, a system for splitting the beam into multiple beams, a

modulation system for the multiple beams, and an optical system that conditions the beams prior to entry to an f- $\theta$  scan lens, an f- $\theta$  scan lens, and an optical relay that re-images a scan line to a final focal plane. For laser direct imaging, the system has high radiometric efficiency, and uses multiple ultraviolet wavelengths  
5 in the beams. Accordingly, optics are achromatized for the ultraviolet wavelengths. In addition, the system has a predominantly reflective architecture for high transmission efficiency.

An active beam steering (ABS) system stabilizes the absolute position of the laser beam before entry into a beamsplitter assembly. The ABS stabilizes the  
10 beam angle and position, and may be used stand-alone or with a second ABS to accommodate a second laser when media sensitivity requires additional laser power. The output of the single or tandem ABS systems maintain beam parallelism with respect to the beamsplitter within one twentieth of the beam diameter, and pointing within one twentieth of the beam divergence angle.

15 A beamsplitter has an architecture that allows simple component replacement or removal during assembly to provide 1, 2, 4, or 8 separate beams, using either 1 or 2 lasers. In addition, the assembly is insensitive to angular alignment errors since each channel is the result of an even number of 90-degree reflections.

20 A primarily reflective optical system compresses the telecentric input beams into the acousto-optic modulator. A reflective system in conjunction with a fused-silica/calcium fluoride doublet provides additional beam forming of a collimated output suitable for use in any scan lens that requires a rotationally-symmetric input beam.

25 An optically coaxial reference timing beam is generated using an unmodulated spectral line emitted by the laser that is not used for imaging.

The output above optical system must travel through a beam rotation device, such as a dove prism. However, due to the achromatic nature of the current invention, a dove prism would introduce unacceptable optical aberration. The

system uses a 3-mirror reflective assembly that creates the same optical condition as a dove prism.

The exemplary system further increases the scan line length. Prior pattern generation systems use about 4,000 pixels in a scan line. Short scan line lengths  
5 require faster polygon speeds and stage velocities than longer scan lines. The exemplary embodiment of the invention images 15,000 pixels per scan line, allowing faster imaging times when limited by stage and polygon velocities.

Absolute pixel placement accuracy is of particular concern with scan lines that have this many pixels. Prior systems addressed this issue using a precision  
10 timing grating parfocal to the image plane. An unmodulated beam is swept across the grating, and collected on a detector. This reference signal, if parfocal to the primary beam, creates a reference clock that is locked to the spatial accuracy of the grating. The exemplary embodiment employs a unique method of injecting, extracting, and imaging the reference optical signal.

15 The system includes an achromatic, catadioptric optical relay. The relay reforms an image from the scan optics, and provides the additional working space for insertion of optical devices including beam position error correction/autofocus optics and a beamsplitter which directs a portion of light from the optical relay to a beam location detector. The optical relay benefits the scan lens design by easing  
20 restrictions of design criteria, namely working distance. The magnification of the scan line can be changed by using a different magnification relay, as is described below for several specific embodiments. In accordance with an aspect of the invention, the optical relay contains primarily reflective elements that provide high transmission efficiency and achromatic focusing of light suitable for  
25 photolithographic processes.

One embodiment of the invention is an optical relay that provides a magnifying power of about unity using spherical mirrors in a configuration that cancels image distortion and spherical aberration. In particular, one embodiment of the optical relay includes: a first concave spherical mirror; a convex spherical  
30 mirror in an optical path of light from the first concave mirror; and a second

concave spherical mirror in an optical path of light from the convex mirror. To cancel aberrations, the first and second concave spherical mirrors have the same radius of curvature while the radius of curvature of the convex mirror is about half the radius of curvature of the concave mirrors.

5 Another embodiment of the invention is an optical relay that employs aspheric mirrors in conjunction with a thick meniscus lens to provides a reduced image size. An exemplary embodiment of the optical relay providing image size reduction includes: a concave parabolic mirror; a convex mirror in an optical path of light from the first concave mirror; and a concave elliptical mirror in an optical  
10 path of light from the convex mirror. An additional lens, which can be adjacent and attached to the convex mirror, corrects image distortion and aberration that may be introduced elsewhere in the optical relay. Other forms of aspheric mirrors may be used to provide different magnifications or other useful properties for the relay system.

15 As an example, a third embodiment of the invention is an optical relay that employs higher-order aspheres in a three-mirror configuration to provide a 2:1 expanded image size.

Embodiments of the optical relays can employ refractive field flatteners if required to compensate for curvature in the image formed by the scan optics. while  
20 maintaining telecentricity.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a block diagram of a laser scanner in accordance with an embodiment of the invention.

25 Figs. 2A, 2B, 2C, and 2D show four separate multi-channel beamsplitters usable in the scanner or Fig. 1.

Fig. 3A shows multi-channel modulator optics for the laser scanner of Fig. 1.

Fig. 3B shows a mirror assembly used instead of a dove prism in an  
30 embodiment of the invention.



Figs. 4A and 4B respectively show a side and perspective view ray trace diagrams of a 1:1 optical relay in accordance with an embodiment of the invention.

Fig. 5 shows an embodiment of the invention in which the relay of Fig. 4A is incorporated within a complete scanner system to provide additional working  
5 distance between the scan optics to the final image.

Fig. 6 shows a detail in optics that directs an unmodulated beam to a parfocal image plane that contains a timing grating.

Fig. 7 and 8 show two relay embodiments usable in the scanner of Fig. 1.

Use of the same reference symbols in different figures indicates similar or  
10 identical items.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A scanner 100 in accordance with an embodiment of the invention shown includes a laser light source 110, an active beam stabilizing (ABS) system 120, a  
15 beam conditioning and modulation system 130, scan optics 150, an optical relay 180, and a stage 190 carrying for a work piece. Laser light source 110 generates a collimated beam 115 of multi-wavelength light. In an exemplary embodiment, laser 110 is a continuous wave laser, and beam 115 has the primary spectral lines occurring at 351 nm, 364 nm and 380 nm. Active beam steering system 120  
20 receives beam 115 and produces a position-stabilized beam 125 to multichannel modulator 130. In an alternative embodiment, laser light source 110 includes two lasers to provide more illumination, and two ABS systems are required for stabilization of beams from both lasers.

Stabilized beam 125 enter multi-channel modulator subsystem 130, where a  
25 beamsplitter assembly separates beam 125 into multiple, telecentric, equal power beams. Figs. 2A, 2B, 2C, and 2D show basic components of beamsplitter configurations to provide 2, 4 or 8 telecentric beams from one or two stabilized input beams 125. Configurations 210, 220, and 230 respectively provide two, four, and eight beams from one input beam. Configuration 240 respectively provides

eight beams from two input beams 125A and 125B. In each configuration 210, 220, 230, and 240, each beam undergoes a multiple of two 90° reflections.

Referring to Fig. 3A, exit beams 235 from configuration 230 are compressed by a factor of 11 using a 3-spherical mirror afocal optical system 310.

5 Mirror system 310 includes two flat folding mirrors 313 and 315 to create a compact layout and three spherical mirrors 312, 314, and 316 for beam compression. A dichroic beamsplitter 320 determines the spectral characteristics of the beams that are separated from the compressed beams from optical system 310 and reflects compressed beams into the acousto-optic modulator (AOM). In  
10 the exemplary embodiment, dichroic beamsplitter 320 reflects light with wavelength 350 to 364 nm to AOM 330. A co-owned U.S. provisional patent application, entitled "ACOUSTO-OPTIC MODULATOR ARRAY WITH REDUCED RF CROSSTALK", Atty. Docket No. P-4296-US, filed July 8, 1997, describes a modulator for the exemplary embodiment of the invention. Modulation  
15 of the laser beam changes the intensities of the individual sub-beams (channels) typically turning sub-beams on and off, but gray scale control of intensities can also be employed for shaping the intensity profile of the scanned image.

Dichroic beamsplitter 320 transmits the 380-nm light from each of the beams. The 380-nm light is folded around AOM 330, where a beam stop 325  
20 blocks all but one channel. The first channel (beam 1) is coaxially combined with the modulated laser light at a dichroic beamsplitter 335. The image of AOM 330 is again compressed by a factor of 6 by a second 3-spherical mirror reflective system 340. At this point, the zero-order beam is blocked, and the first order beam from AOM 330 continues and expands, to be collimated by a fused-silica/calcium  
25 fluoride doublet 350. The beam is then folded through a reflective mirror structure 390 that is shown in Fig. 3B and used to rotate the multiple channels.

Returning to Fig. 1, scan optics system 150 includes anamorphic pre-polygon beam optics 152, a rotating polygon mirror 154, and catadioptric scan lens elements 156. To move the image along a scan direction, polygon mirror 154  
30 rotates about an axis which changes the angles of incidence and reflection of the

beams from modulator 130. Scan lens 156 focuses the beam bundle to reduce the separation between separate sub-beams and tightly focus each sub-beam. In the exemplary embodiment, scan lens 156 provides an anamorphic magnification between the scan direction and the cross-scan direction so that errors in the bearings supporting polygon mirror 154 are reduced in effect. A co-owned U.S. provisional patent application, attorney docket No. P-4295, entitled "Anamorphic, Catadioptric Scan Lens for Laser Scanner", which is hereby incorporated by reference in its entirety describes the operation of scan lens 156.

Optical scanning system 100 includes optical relay 180 in accordance with an aspect of the invention. Optical relay 180 reforms the image formed by scan optics 150, and may be used to reduce the constraints on certain scan lens performance requirements, allowing scan optics 150 to achieve better performance in other areas. With the exemplary embodiment described, working distance of the scan optics 150 (distance from last lens element to the focal plane) is allowed to be small (i.e., insufficient for clearance of a workpiece and other optical elements required in the system.) With this modified constraint, telecentricity, increased  $f\#$  (decreased spot size), and differential distortion requirements can be met without increasing the complexity and reducing transmission efficiency of scan optics 150.

The working distance is regained without significant loss of transmission by use of the predominantly reflective relay. Increased working distance is required to accommodate stage working distance requirements, beamsplitters for optical sensors and timing systems, and/or image correction optics. Co-owned U.S. provisional patent application, attorney docket No. M-4291, entitled "Chevron Error Correction for Bi-directional Raster Scanning", filed July 8, 1997, which is hereby incorporated by reference in its entirety describes image correction optics which may be inserted in the optical path of optical relay 180. In addition to increased working distance, relay 180 can scale the spot size and length of the scan line to match the system performance requirements. Three specific embodiments of relays are described below. Of particular note is the implementation of beamsplitters and sensors used to create system timing.

Figs. 4A and 4B shows an exemplary embodiment of an optical relay 400. Optical relay 400 has magnifying power of about 1 and is sometimes referred to herein as a 1:1 optical relay. The object for optical relay 400 is the image formed by the scan lens. Accordingly, the object moves during scanning. Fig. 4B shows  
5 rays emerging from three separate object locations 401, 402, and 403 on a line 405.

Optical relay 400 includes a field flattener (lens) 410, a first concave spherical mirror 420, a convex spherical mirror 430, and a second concave spherical mirror 440. Field flattener 410 compensates for field curvature which may exist along line 405 where the scan lens forms images. Divergent rays from  
10 field flattener 120 are incident on a surface 422 of concave spherical lens 220 which reflects the rays onto surface 432 of convex spherical mirror 430. Rays which are converging upon incidence to convex mirror 430 are divergent after reflection from surface 432. A surface 442 of concave mirror 440 focuses the divergent rays from convex mirror 430 to an image line 450. Objects at locations  
15 401, 402, and 403 on line 405 result in images at locations 451, 452, and 453, respectively, on line 450.

The location of image line 450 relative to line 405 depends on the radii and positions of mirrors 420, 430, and 440. In an exemplary, embodiment of the invention, concave mirrors 420 and 440 have the same radius of curvature, and  
20 mirror 430 has a radius that is about half the radius of mirror 420 or 440. In this exemplary embodiment, spherical aberrations from the spherical mirrors 420, 430, and 440 cancel each other. Other critical parameters include the angle subtended by mirrors 420 and 440 from line 405 and 450 respectively and the angle between mirrors 420 and 440 with mirror 430 at a vertex. These angles control the size of  
25 the scan field and the speed (f number) of optical relay 400.

Fig. 5 illustrates an application of optical relay 400 in a scanner 500. As shown in Fig. 5, line 405 is relatively close to an optical element 505 of the scan lens which forms an image at line 405 so that there is insufficient workings space between element 505 and line 405 for insertion of optical devices. Accordingly,  
30 optical relay 400 is employed to reform the image on line 450. Field flattener 410

directs diverging light from line 405 to folding mirrors 510 and 515. Folding mirrors 510 and 515 are positioned according to the available geometry of scanner 500 and direct light from field flattener 410 to concave mirror 420. From concave mirror 420, light passes to convex mirror 430 and then concave mirror 440 which  
5 focuses the light.

The distance from mirror 440 to image line 450 is much greater than the distance between optical element 505 and line 405. This allows optical elements such as beamsplitters, a chevron correction prism 560, and autofocus optics to be inserted into the optical path in optical relay 400 between element 440 and the final  
10 image plane 450. Fig. 5 illustrates the impact of adding these elements to the system.

Fig. 6 shows a chevron prism 560. In chevron prism 560, an input beam 605 is incident on a prism 610. A primary write beam (350-364 nm light) reflects off of a surface 611 which transmits the unmodulated optical timing signal whose  
15 wavelength is 380 nm. This timing signal reflects off of base 612 of the prism 610. The reflected rays then reflect (through Total Internal Reflection) off of the incident surface 611, and out through surface 613. The bundle forms a tilted line focus (parallel to the grating lines) on the timing grating, 570. This prism fold technique has two advantages. First, the package size is conserved. Second, the  
20 line focus on the grating will integrate out the effects of defects and small dust particles on the chrome-on-glass grating, providing a more robust timing system. In addition to the timing grating, the timing system utilizes a start-of-scan detector that receives part of the light off of beamsplitter 640.

Chevron correction system and a chevron sensor system includes of a 0.5%  
25 transmissive final fold mirror 630, a magnifying UV objective lens, and a CCD camera 580 for sensing position and focus of the beam at a parfocal yet magnified image plane.

Optical relay 180 can also reduce the image size to provide a higher resolution scan beam. Fig. 7 illustrates an optical relay 700 which has a  
30 magnification less than 1 and reduces the image size. Optical relay 700 includes a

field flattener (lens) 710, a first aspherical concave mirror 720, a convex mirror 730, a second aspherical concave mirror 750, and a meniscus lens 750. Field flattener 710 balances distortion errors and field curvature created by the scan lens which forms an image on line 405. Line 705 is located near an edge of field flattener 710 which allows field flattener 710, convex mirror 730, and lens 750 to have a common optical axis.

Light from field flattener 710 is incident on a surface 722 of aspherical concave mirror 720 which in an exemplary embodiment of the invention, has a parabolic surface 722. Mirror 720 directs light to mirror 730 which has a diameter that defines a stop size for relay 700. Rays which are convergent after reflection from surface 722 are divergent after reflection from convex mirror 730. Aspherical concave mirror 740 and lens 750 focus the light reflected by convex mirror 730. In the exemplary embodiment, mirror 740 has an elliptical surface 742, and lens 750 corrects for image distortion and aberrations created in optical relay 700. The specific aspheric required to correct image errors and distortion will depend upon the magnification of the relay lens.

Fig. 8 shows a magnifying optical relay 800 which is entirely reflective for high transmission efficiency. Optical relay 800 includes a first concave aspheric mirror 810 which receives light from an image 805 of a scan lens, a convex spherical mirror 820, and a second concave aspheric mirror 830 which focuses the final image 835. To provide the necessary corrections for field curvature, aspheric mirrors 810 and 830 can be higher-order aspheres, for example fifth order aspheres in an exemplary embodiment. The appendix provides a "Code V" lens prescription listing of the surface parameters for a 1:2 magnifying optical relay of Fig. 8.

The appendix also provides "Code V" lens prescription listings of the surface parameters for the 1:1 relay of Figs. 4A and 4B, and a 2.5:1 reducing optical relay of Fig. 7.

Although the invention has been described with reference to particular embodiments, the description is only an example of the invention's application and should not be taken as a limitation. Various adaptations and combinations of

features of the embodiments disclosed are within the scope of the invention as defined by the following claims.

## APPENDIX

## 1:1 Reduction Afocal Relay

	RDY	THI	RMD	GLA	CCY	THC
OBJ:	INFINITY	0.000000			100	100
1:	INFINITY	0.000000			100	100
2:	INFINITY	0.000000			100	100
3:	INFINITY	0.000000			100	100
4:	INFINITY	0.500065			100	100
5:	-7.24800	0.316136		SILICA_SPECIAL	100	100
TRN:	0.999000	0.99900	0.99900			
6:	-7.13400	0.000000			100	100
7:	INFINITY	5.413781			100	100
XDE:	-1.469982	YDE:	0.000000	ZDE:	0.000000	
XDC:	100	YDC:	100	ZDC:	100	
ADE:	0.000000	BDE:	0.000000	CDE:	0.000000	
ADC:	100	BDC:	100	CDC:	100	
8:	INFINITY	0.000000			100	100
9:	INFINITY	0.000000			100	100
CUM:	0.000000	THM:	0.25000	GLM:		
10:	INFINITY	2.338195			100	100
11:	INFINITY	0.000000			100	100
12:	INFINITY	0.000000			100	100
SLB:	"RFM2"					
CUM:	0.000000	THM:	0.500000	GLM:		
13:	INFINITY	3.612879			100	100
14:	INFINITY	0.000000			100	100
XDE:	1.446330	YDE:	0.000000	ZDE:	0.000000	
XDC:	100	YDC:	100	ZDC:	100	
ADE:	0.000000	BDE:	-5.604311	CDE:	0.000000	
ADC:	100	BDC:	100	CDC:	100	
15:	-11.60000	0.000000	REFL		100	100
SLB:	"RM1"					
CUM:	0.000000	THM:	1.000000	GLM:		
16:	INFINITY	-5.388191			100	100
XDE:	0.000000	YDE:	0.000000	ZDE:	0.000000	
XDC:	100	YDC:	100	ZDC:	100	
ADE:	0.000000	BDE:	-5.604311	CDE:	0.000000	
ADC:	100	BDC:	100	CDC:	100	
17:	INFINITY	-0.341993			100	100
18:	INFINITY	0.000000			100	100
XDE:	0.014409	YDE:	0.000000	ZDE:	0.000000	
XDC:	100	YDC:	100	ZDC:	100	
ADE:	0.000000	BDE:	11.134474	CDE:	0.000000	
ADC:	100	BDC:	100	CDC:	100	
STO:	-5.81350	0.000000	REFL		100	100
SLB:	"RM2"					
CUM:	0.000000	THM:	0.400000	GLM:		
20:	INFINITY	0.341993			100	100
XDE:	0.000000	YDE:	0.000000	ZDE:	0.000000	
XDC:	100	YDC:	100	ZDC:	100	
ADE:	0.000000	BDE:	11.134474	CDE:	0.000000	
ADC:	100	BDC:	100	CDC:	100	
21:	INFINITY	5.483191			100	100



22:	INFINITY	0.000000	100	100
	XDE: 0.014340	YDE: 0.000000	ZDE: 0.000000	
	XDC: 100	YDC: 100	ZDC: 100	
	ADE: 0.000000	BDE: -5.757138	CDE: 0.000000	
	ADC: 100	BDC: 100	CDC: 100	
23:	-11.60000	0.000000	REFL	100 100
	SLB: "RM3"			
	CUM: 0.000000	THM: 1.000000	GLM:	
24:	INFINITY	0.000000	100	100
	XDE: 0.000000	YDE: 0.000000	ZDE: 0.000000	
	XDC: 100	YDC: 100	ZDC: 100	
	ADE: 0.000000	BDE: -5.757138	CDE: 0.000000	
	ADC: 100	BDC: 100	CDC: 100	
25:	INFINITY	-6.915399	100	100
	XDE: -0.123178	YDE: 0.000000	ZDE: 0.000000	
	XDC: 100	YDC: 100	ZDC: 100	
	ADE: 0.000000	BDE: 0.501616	CDE: 0.000000	
	ADC: 100	BDC: 100	CDC: 100	
26:	INFINITY	0.000000	100	100
27:	INFINITY	0.000000	100	100
28:	INFINITY	-4.220250	100	PIM
IMG:	INFINITY	0.000000	100	100

## SPECIFICATION DATA

NAO	0.04000		
PUX	0.75000		
PUY	0.75000		
PUI	0.13500		
TEL			
DIM	IN		
WL	363.80	351.40	351.10
REF	2		
WTW	100	100	100
XOB	0.00000	0.00000	0.00000
YOB	0.00000	1.00000	1.500000
VUX	0.00000	0.00000	0.00000
VLX	0.00000	0.00000	0.00000
VUY	0.00000	0.00000	0.00000
VLY	0.00000	0.00000	0.00000
PFR	1.0000	1.0000	1.0000
PTP	0.0000	0.0000	0.0000
POR	0.0000	0.0000	0.0000
PRO	LIN	LIN	LIN

## APERTURE DATA/EDGE DEFINITIONS

CA	
REX S6	0.200000
REY S6	1.875000
REX S9	0.400000
REY S9	1.875000
ADX S9	2.700000
REX S12	0.500000
REY S12	2.000000
ADX S12	1.600000

REX S15	0.600000
REY S15	2.075000
CIR S19	0.550000
REX S23	0.600000
REY S23	2.075000

## REFRACTIVE INDICES

GLASS CODE	363.80	351.40	351.10
SILICA_SPECIAL	1.474723	1.476662	1.476712

## SOLVES

PIM

No pickups defined in system

This is a decentered system. If elements with power are decentered or tilted, the first order properties are probably inadequate in describing the system characteristics.

## INFINITE CONJUGATES

EFL	1514.9226
BFL	-1516.7689
FFL	-1517.3004
FNO	0.0000

## AT USED CONJUGATES

RED	0.9984
FNO	12.4804
OBJ DIS	0.0000
TT	1.1404
IMG DIS	-4.2202
OAL	5.3607

## PARAXIAL IMAGE

HT	1.4976
THI	-4.2202
ANG	0.0000

## ENTRANCE PUPIL

DIA	0.8006E+09
THI	0.1000E+11

## EXIT PUPIL

DIA	121.2909
THI	-1516.7687

CODE V> out t

CODE V&gt; list

## 2.5:1 Reduction Relay

	RDY	THI	RMD	GLA	CCY	THC
OBJ:	INFINITY	0.000000			100	100
1:	INFINITY	0.000000			100	100
2:	INFINITY	0.000000			100	100
3:	INFINITY	0.017544			100	0
	XDE: 2.718028	YDE: 0.000000	ZDE: 0.000000			
	XDC: 1	YDC: 100	ZDC: 100			
	ADE: 0.000000	BDE: 0.000000	CDE: 0.000000			
	ADC: 100	BDC: 100	CDC: 100			
4:	17.05165	0.450000		SILICA_SPECIAL	100	100
	SLB: "L_1"					
5:	81.06929	1.750000			100	100
6:	INFINITY	9.823047			100	0
7:	INFINITY	6.724474			100	100
8:	INFINITY	0.000000			100	100
9:	INFINITY	0.000000			100	0
	SLB: "FM_3"					
	CUM: 0.000000	THM: 0.000000	GLM:			
10:	INFINITY	3.064582			100	100
11:	INFINITY	2.000000			100	100
12:	INFINITY	0.000000			100	100
13:	-18.01000	-6.355217	REFL		100	0
	SLB: "M_1"					
	CON:					
	K: -1.000000	KC: 100				
	CUM: 0.000000	THM: 1.000000	GLM:			
14:	INFINITY	0.000000			100	100
STO:	-6.79736	6.461636	REFL		100	-1
	SLB: "M_2"					
	CUM: -0.292620	THM: 0.225000	GLM:			
16:	INFINITY	0.000000			100	100
17:	-11.34300	-6.461636	REFL		100	1
	SLB: "M_3"					
	CON:					
	K: 0.079573	KC: 0				
	CUM: 0.000000	THM: 1.000000	GLM:			
18:	INFINITY	0.000000			100	100
19:	INFINITY	-0.225000			100	100
20:	-3.41740	-0.647799		BK_SCHOTT	100	0
	SLB: "L_2"					
21:	-2.85677	0.000000			100	100
22:	INFINITY	0.000000			100	100
	XDE: 1.087230	YDE: 0.000000	ZDE: 0.000000			
	XDC: 100	YDC: 100	ZDC: 100			
	ADE: 0.000000	BDE: 0.000000	CDE: 0.000000			
	ADC: 100	BDC: 0	CDC: 100			
23:	INFINITY	0.000000			100	100
24:	INFINITY	0.000000			100	100
25:	INFINITY	-3.670777			100	PIM
IMG:	INFINITY	-0.000043			100	100

## SPECIFICATION DATA

NAO	0.04500				
PUX	0.75000				
PUY	0.75000				
PUI	0.13500				
TEL					
DIM	IN				
WL	363.80	351.40	351.10		
REF	2				
WTW	100	100	100		
XOB	-0.01000	-0.01000	0.00000	0.01000	0.01000
	0.01000				
YOB	-1.75000	-1.25000	0.00000	0.50000	0.75000
	1.50000				
VUX	0.00000	0.00000	0.00000	0.00000	0.00000
	0.00000				
VLX	0.00000	0.00000	0.00000	0.00000	0.00000
	0.00000				
VUY	0.00000	0.00000	0.00000	0.00000	0.00000
	0.00000				
VLY	0.00000	0.00000	0.00000	0.00000	0.00000
	0.00000				
PFR	1.0000	0.0000	0.0000	0.0000	0.0000
	0.0000				
PTP	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000				
POR	90.0000	0.0000	0.0000	0.0000	0.0000
	0.0000				
PRO	LIN	LIN	LIN	LIN	LIN
	LIN				

## APERTURE DATA/EDGE DEFINITIONS

CA	
CIR S4	3.400000
CIR S5	3.600000
REX S13	1.250000
REY S13	1.250000
ADX S13	-1.500000
CIR S15	0.600000
REX S17	1.400000
REY S17	1.400000
ADX S17	1.400000
REX S20	1.250000
REY S20	1.250000
ADX S20	0.500000
REX S21	0.900000
REY S21	0.900000
ADX S21	0.500000

## REFRACTIVE INDICES

GLASS CODE	363.80	351.40	351.10
SILICA SPECIAL	1.474723	1.476662	1.476712
BK7_SCHOTT	1.536487	1.538878	1.538940

SOLVES

CODE V&gt; list

1:2 Relay, Unfolded

	RDY	THI	RMD	GLA	CCY	THC
OBJ:	INFINITY	0.000000			100	100
1:	INFINITY	9.606462			100	100
XDE:	0.849944	YDE:	0.000000	ZDE:	0.000000	
XDC:	100	YDC:	100	ZDC:	100	
ADE:	0.000000	BDE:	0.000000	CDE:	0.000000	
ADC:	100	BDC:	100	CDC:	100	
2:	-10.94345	0.000000	REFL		0	100
SLB:	"m1"					
ASP:						
K :	0.129314	KC :	0			
IC :	YES	CUF:	0.000000	CCF:	100	
A :	0.000000E+00	B :	-.125417E-06	C :	0.000000E+00	D : 0.000000E+00
AC :	100	BC :	0	CC :	100	DC : 100
CUM:	0.000000	THM:	0.500000	GLM:		
3:	INFINITY	-5.486081			100	100
STO:	-7.28887	0.000000	REFL		0	100
SLB:	"m2"					
CUM:	0.000000	THM:	0.250000	GLM:		
5:	INFINITY	10.362644			100	100
6:	-21.17519	0.000000	REFL		0	100
SLB:	"m3"					
ASP:						
K :	-0.209402	KC :	0			
IC :	YES	CUF:	0.000000	CCF:	100	
A :	0.000000E+00	B :	-.538804E-08	C :	0.000000E+00	D : 0.000000E+00
AC :	100	BC :	0	CC :	100	DC : 100
CUM:	0.000000	THM:	1.000000	GLM:		
7:	INFINITY	-26.315719			100	PIM
XDE:	1.673560	YDE:	0.000000	ZDE:	0.000000	
XDC:	100	YDC:	100	ZDC:	100	
ADE:	0.000000	BDE:	0.000000	CDE:	0.000000	
ADC:	100	BDC:	100	CDC:	100	
IMG:	INFINITY	0.000000			100	100

## SPECIFICATION DATA

NAO	0.06375				
PUX	0.58800				
PUY	0.58800				
PUI	0.13500				
TEL					
DIM	IN				
WL	387.00	365.00	350.00		
REF	2				
WTW	33	33	33		
INI	RAI				
XOB	0.00000	0.00000	0.00000	0.01500	0.01500
	0.01500	0.00000	0.00000		
YOB	-1.60000	1.60000	0.00000	-1.60000	1.60000
	0.00000	-1.12000	1.12000		
VUX	0.00000	0.00000	0.00000	0.00000	0.00000
	0.00000	0.00000	0.00000		
VLX	0.00000	0.00000	0.00000	0.00000	0.00000
	0.00000	0.00000	0.00000		
VUY	0.00000	0.00000	0.00000	0.00000	0.00000
	0.00000	0.00000	0.00000		
VLY	0.00000	0.00000	0.00000	0.00000	0.00000
	0.00000	0.00000	0.00000		

## APERTURE DATA/EDGE DEFINITIONS

CA		
REX S2		0.650000
REY S2		2.250000
ADX S2		-0.850000
CIR S4		0.400000
REX S6		0.925000
REY S6		4.050000
ADX S6		1.635370
REX S2	EDG	0.750000
REY S2	EDG	2.500000
ADX S2	EDG	-0.950000
CIR S4	EDG	0.500000
REX S6	EDG	1.050000
REY S6	EDG	4.250000
ADX S6	EDG	1.710000

No refractive materials defined in system

## SOLVES

PIM

No pickups defined in system

This is a decentered system. If elements with power are decentered or titled, the first order properties are probably inadequate in describing the system characteristics.

## INFINITE CONJUGATES

EFL	-273.9348
BFL	521.5540
FFL	136.9674
FNO	0.0000

## AT USED CONJUGATES

RED	2.0000	
FNO	15.6863	
OBJ	DIS	0.0000
TT	-11.8327	
ING	DIS	-26.3157
OAL	14.4830	

## PARAXIAL IMAGE

HT	2.2400
THI	-26.3157
ANG	0.0000

## ENTRANCE PUPIL

DIA	0.1278E+10
THI	0.1000E+11

## EXIT PUPIL

DIA	34.9979
THI	521.5540

We claim:

1. A laser direct imaging system comprising:
  - a multi-wavelength laser generates a beam;
  - an active beam stabilization system;
  - 5 means for splitting the beam into sub-beams;
  - a reflector that telecentrically reduces diameters of the sub-beams;
  - a multi-channel beam modulation device;
  - a beamsplitter for splitting and recombining one sub-beam of a different UV spectral line to be used to generate a timing signal;
  - 10 a catadioptric optics that collimate the sub-beams;
  - a reflector that rotates the sub-beams;
  - a telecentric scan lens;
  - an afocal relay; and
  - means for extracting the unmodulated optical timing signal
  - 15 incorporation of chevron correction optics within the relay system.
2. The system of claim 1, wherein the beamsplitter consists of a multiple beamsplitter configuration such that 2, 4, or 8 beams can be generated using the same subset of components, such that each sub-beam results from a multiple of  
20  $2 \times N$  90 degree reflections, N being an arbitrary number.
3. The system of claim 1, wherein the timing signal is generated by first reflecting 350-364 nm light off of the front surface of a beamsplitter immediately prior to the modulating device, while passing 380nm and above, and second,  
25 blocking all but one of the transmitted beams, and third, coaxially combining the resultant timing beam with the write beam immediately after the modulating device using an identical second beamsplitter.
4. The relay of claim 1 wherein refractive optical elements are included as  
30 correcting elements.

5. A reflective optical relay used to reform a stripe image field from a photolithographic scan lens that maintains correction of the following parameters:  
diffraction limited (Strehl ratio > 75%);  
5 maintains a telecentric, flat-field image plane; and  
minimized differential distortion within the required tolerance for a multiple-beam system.

6. An optical relay comprising in order from an object to an image side:  
10 a field flattener;  
a first concave mirror in an optical path from the field flattener;  
a convex mirror in an optical path from the first concave mirror; and  
a second concave mirror in an optical path from the convex mirror.

7. The optical relay of claim 6, wherein:  
15 each of the first and second concave mirrors has a concave spherical surface; and  
a radius of curvature of the first concave spherical mirror is the same as a radius of curvature of the second concave spherical mirror.

8. The optical relay of claim 7, wherein the convex mirror has a spherical surface with a radius of curvature that is about half the radius of curvature of the first concave mirror.

9. The optical relay of claim 8, wherein the optical relay has a magnifying power of about 1.

10. The optical relay of claim 6, wherein:  
each of the first and second concave mirrors has an aspherical  
30 surface; and



the optical relay further comprises a lens in an optical path from the second concave mirror, wherein the lens corrects distortion or aberration created elsewhere in the optical relay.

5 11. The optical relay of claim 10, wherein:

the aspherical surface of the first concave mirror has a parabolic cross-section; and

the aspherical surface of the second concave mirror has an elliptical cross-section.

10

12. The optical relay of claim 11, wherein the optical relay has a magnifying power of less than 1.

13. A laser scanner comprising:

15

a source of a spatially modulated laser beam;  
scan optics which forms an image of the spatially modulated laser beam, wherein the image has a location that moves along a first line; and  
an optical relay comprising in order from an object side to an image side:

20

a field flattener positioned to receive light from the image located on the first line;

a first concave mirror in an optical path from the field flattener;

25

a convex mirror in an optical path from the first concave mirror; and

a second concave mirror in an optical path from the convex mirror, wherein the second concave mirror forms an image having a location that moves along a second line.

30

14. The laser scanner of claim 13, wherein:

each of the first and second concave mirrors has a concave spherical surface; and

a radius of curvature of the first concave spherical mirror is the same as a radius of curvature of the second concave spherical mirror.

5

15. The laser scanner of claim 14, wherein the convex mirror has a spherical surface with a radius of curvature that is about half the radius of curvature of the first concave mirror.

10

16. The laser scanner of claim 15, wherein the optical relay has a magnifying power of about 1.

17. The laser scanner of claim 13, wherein:

15

each of the first and second concave mirrors has an aspherical surface; and

the optical relay further comprises a lens in the optical path of light reflected from the second concave mirror, wherein the lens corrects distortion or aberration created elsewhere in the optical relay.

20

18. The laser scanner of claim 17, wherein:

the aspherical surface of the first concave mirror has a parabolic cross-section; and

the aspherical surface of the second concave mirror has an elliptical cross-section.

25

19. The laser scanner of claim 18, wherein the optical relay has a magnifying power of less than 1.

20. A laser scanner comprising:

30

a source of a spatially modulated laser beam;

scan optics which forms a first image of the spatially modulated laser beam, wherein the first image has a location that moves along a first line;

a beam location detector;

5 an optical relay that forms from the first image, a second image having a location that moves along a second line; and

a beamsplitter located in an optical path of the optical relay, wherein the beamsplitter separates a portion of light from the optical relay for the beam location detector.

10

21. The scanner of claim 20, further comprising chevron correction optics located in the optical path of the optical relay.

22. The scanner of claim 20, wherein the optical relay has a magnifying  
15 power of about 1.

23. The scanner of claim 20, wherein the optical relay has a magnifying power less than 1.

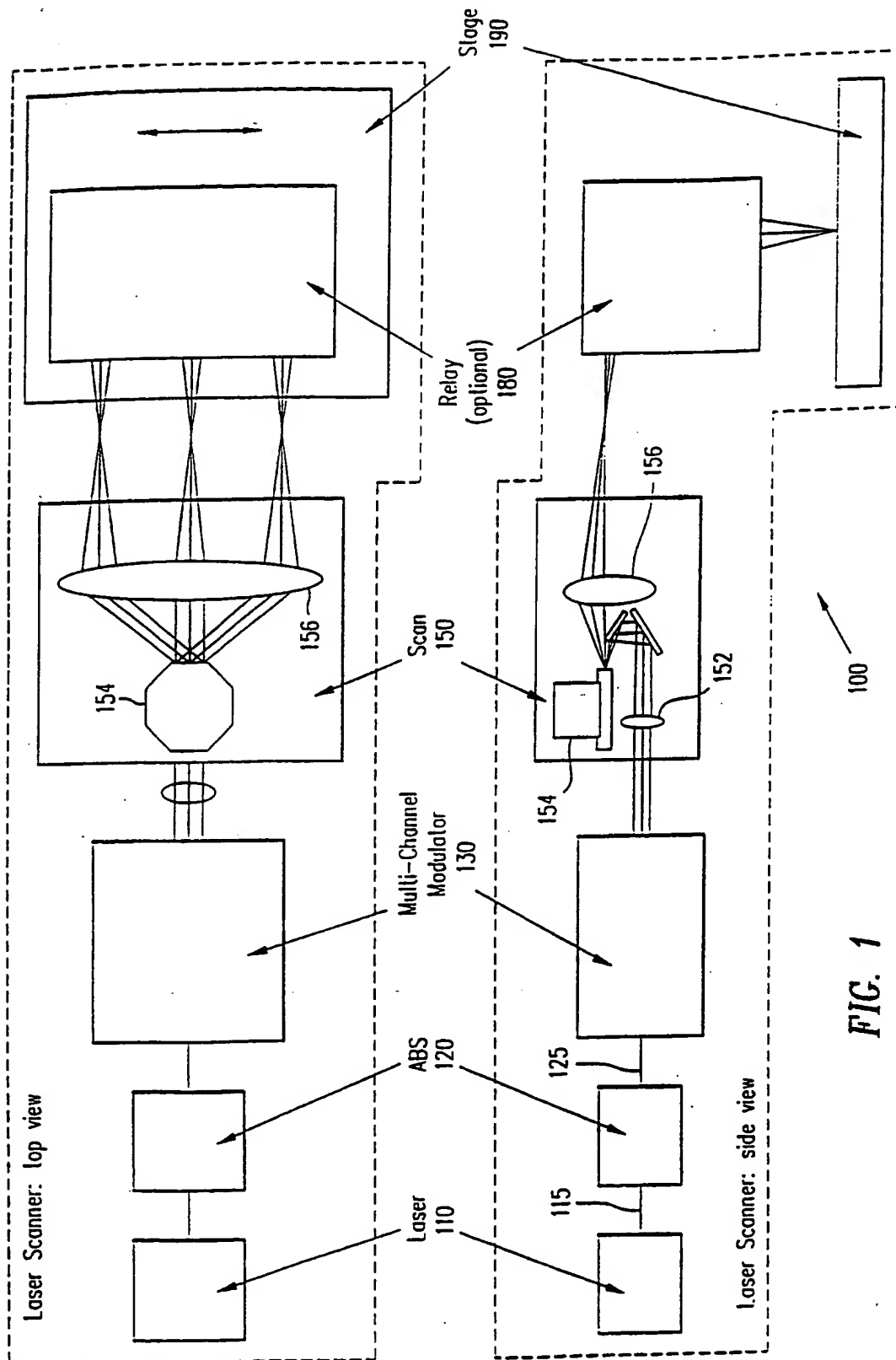
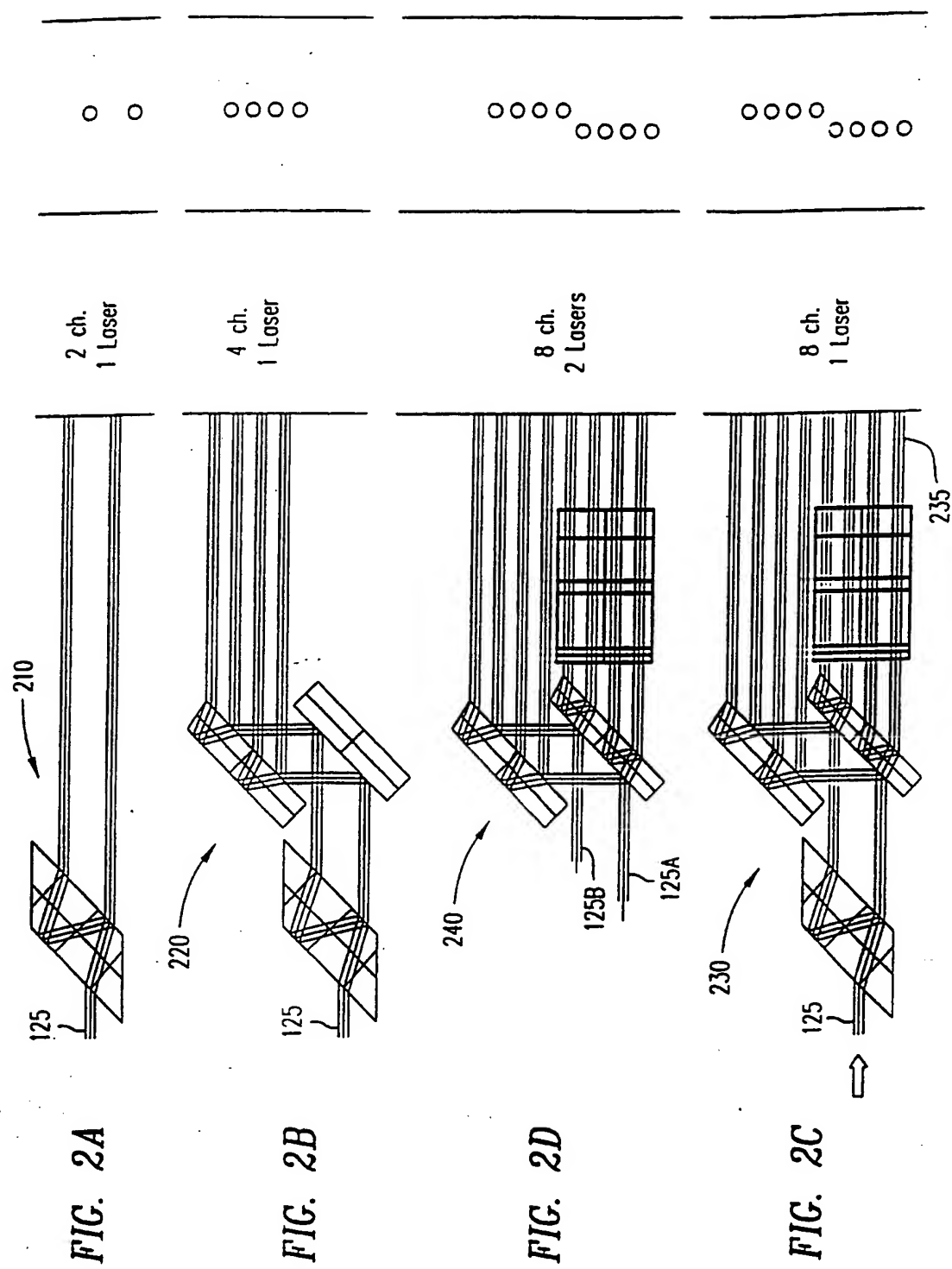


FIG. 1



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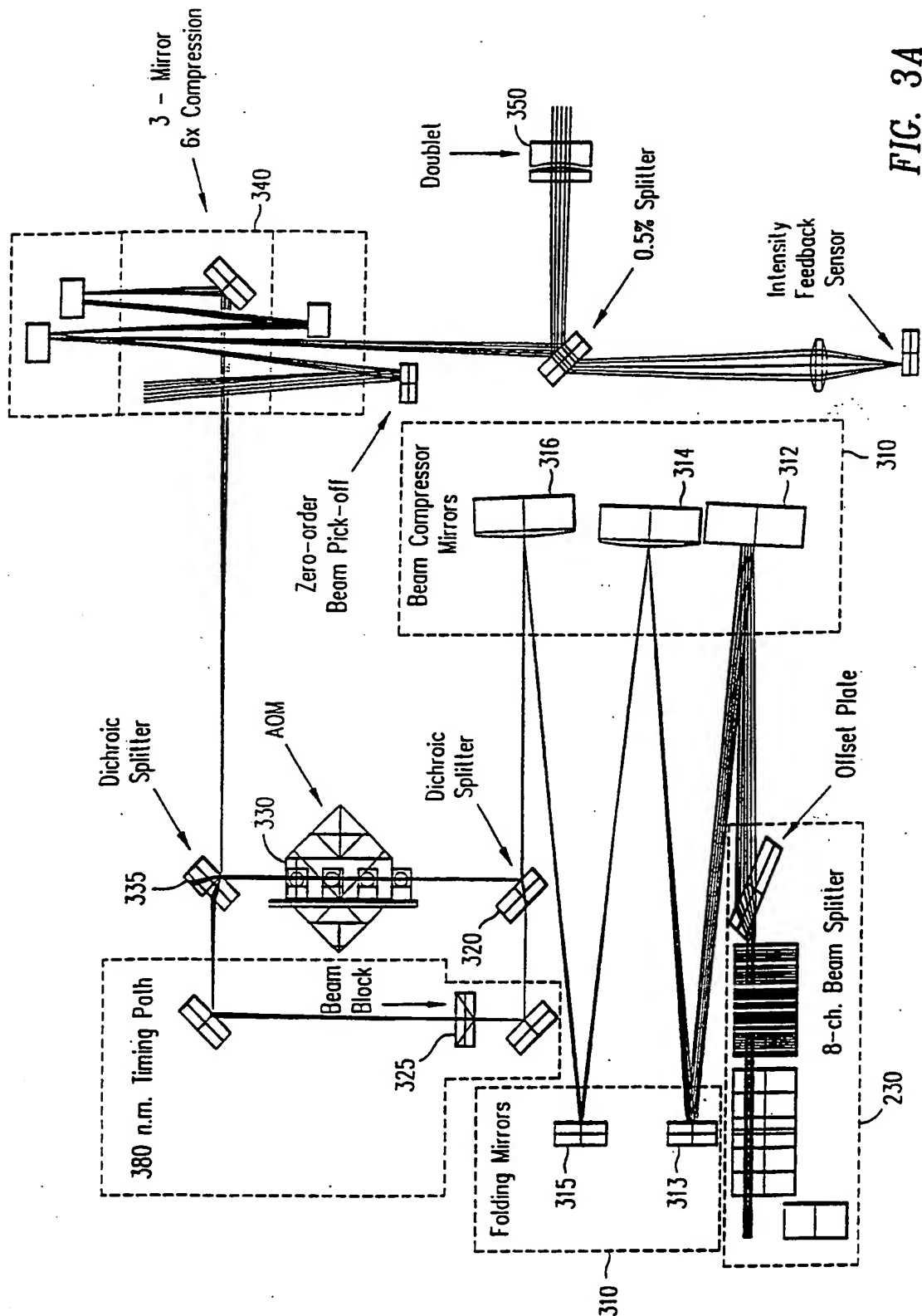


FIG. 3A

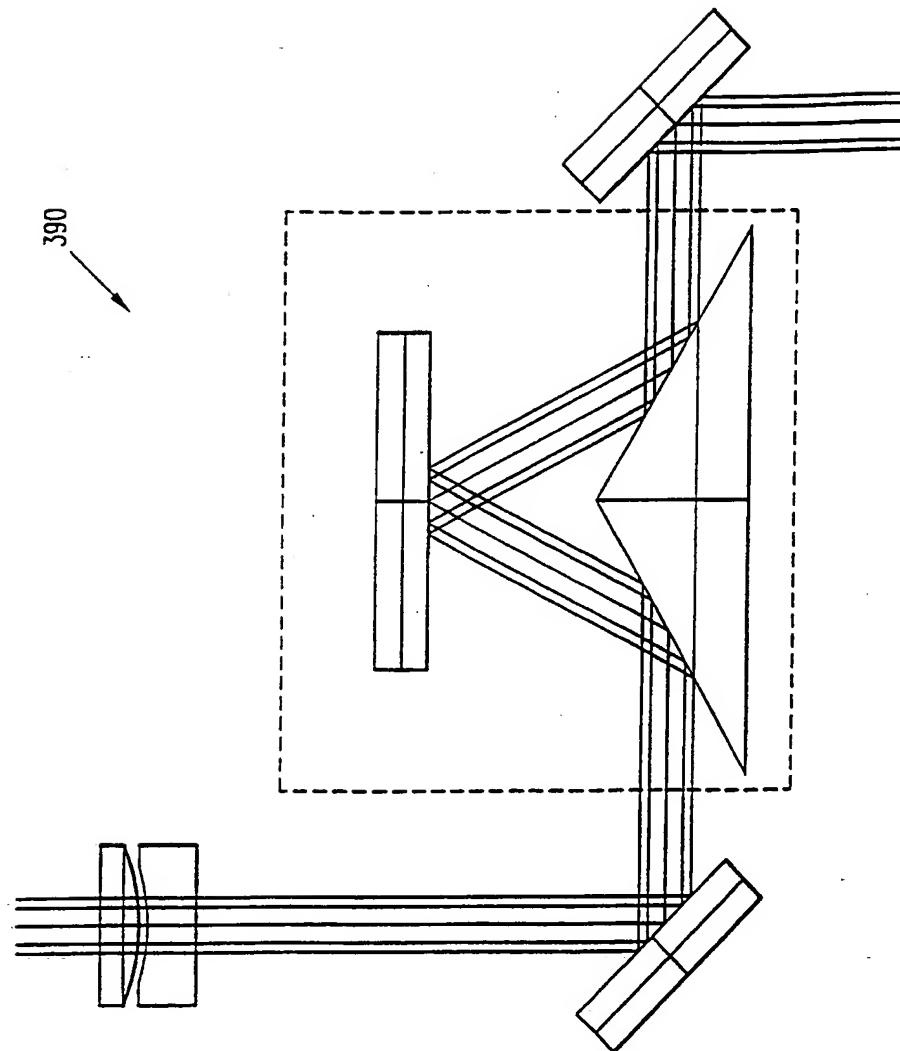


FIG. 3B

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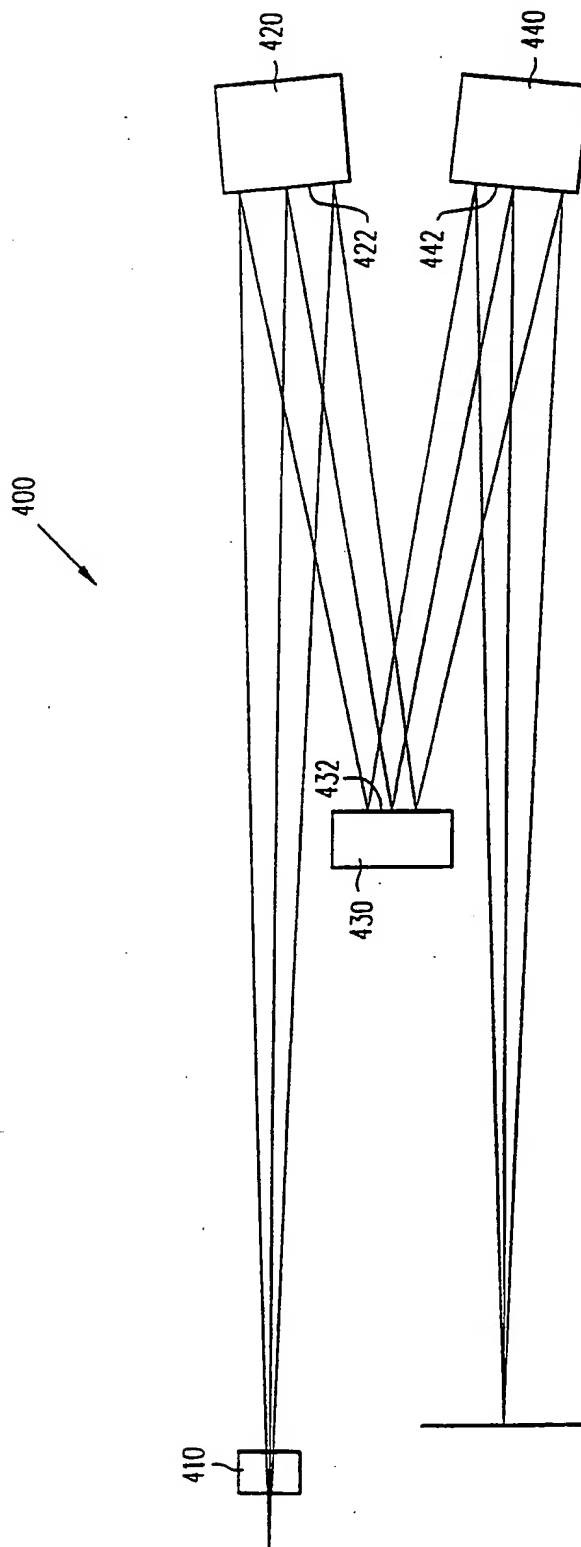


FIG. 4A



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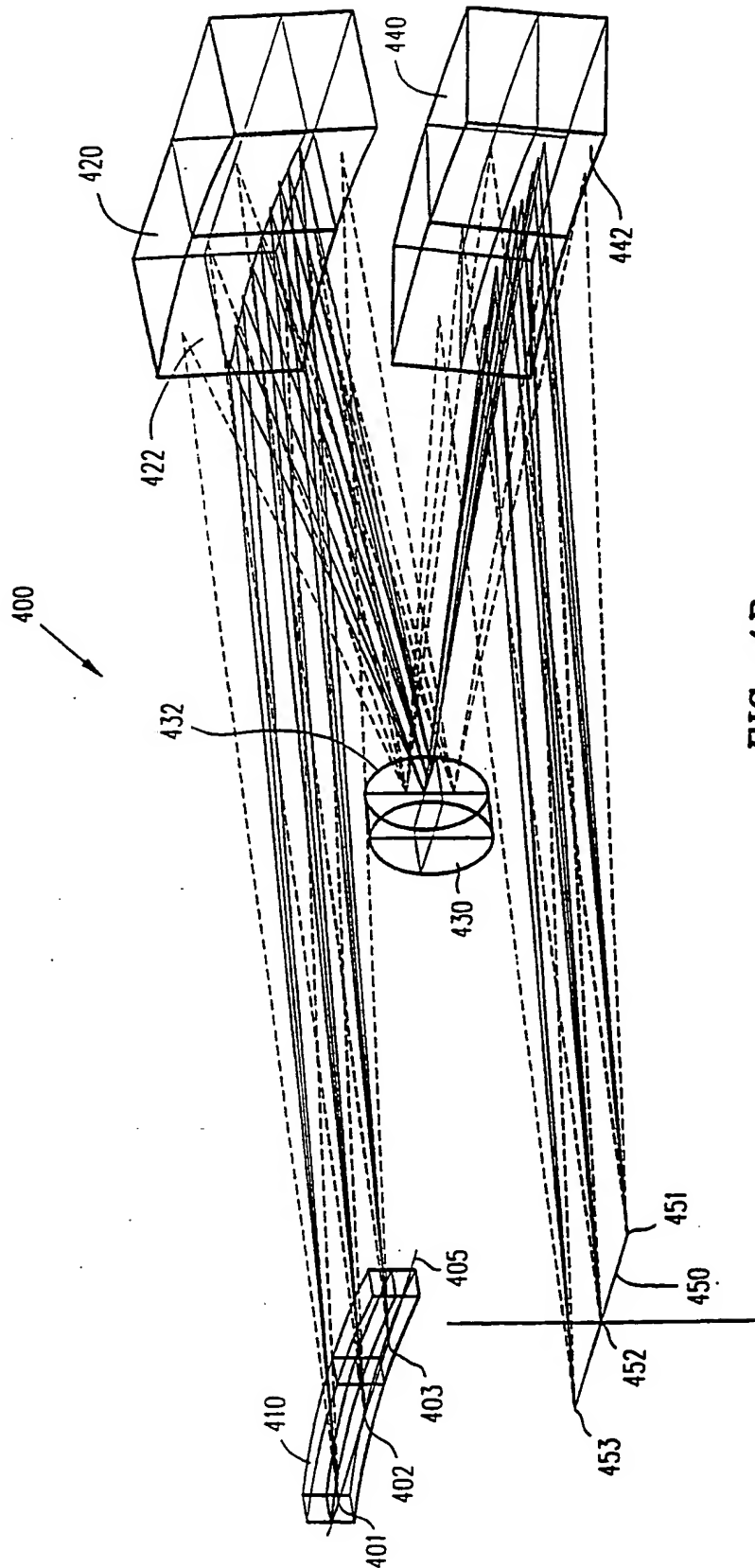


FIG. 4B

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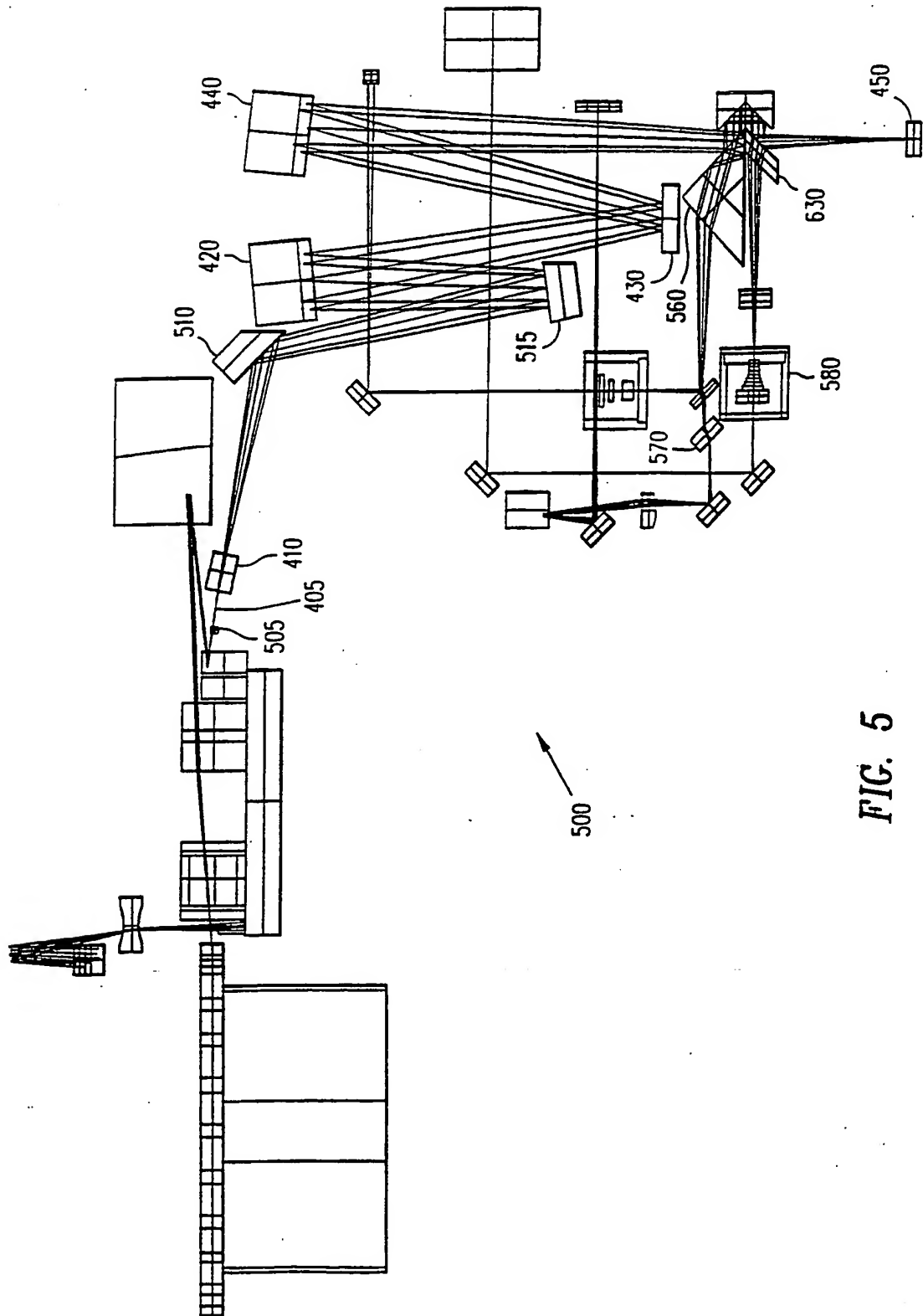


FIG. 5

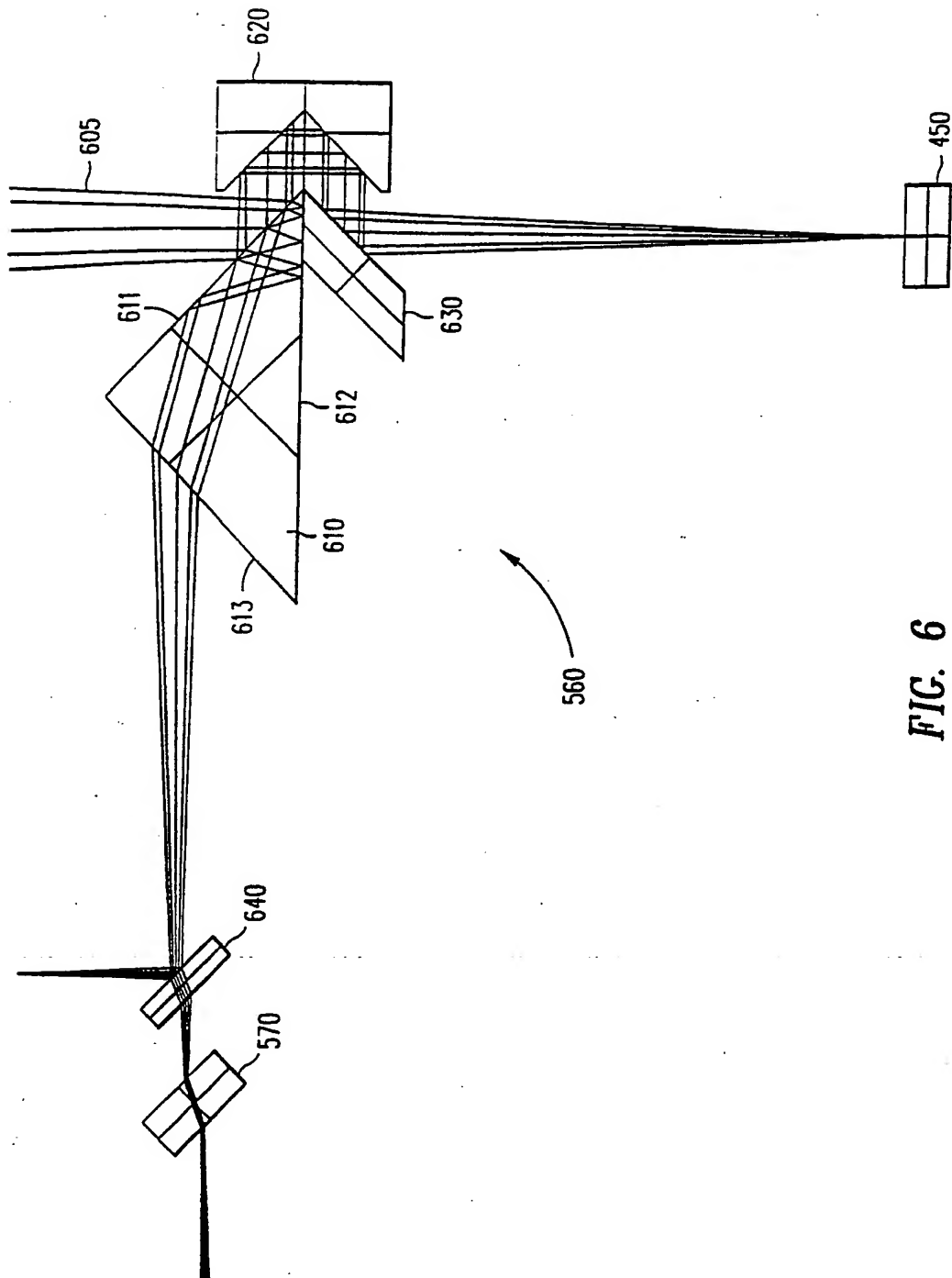


FIG. 6

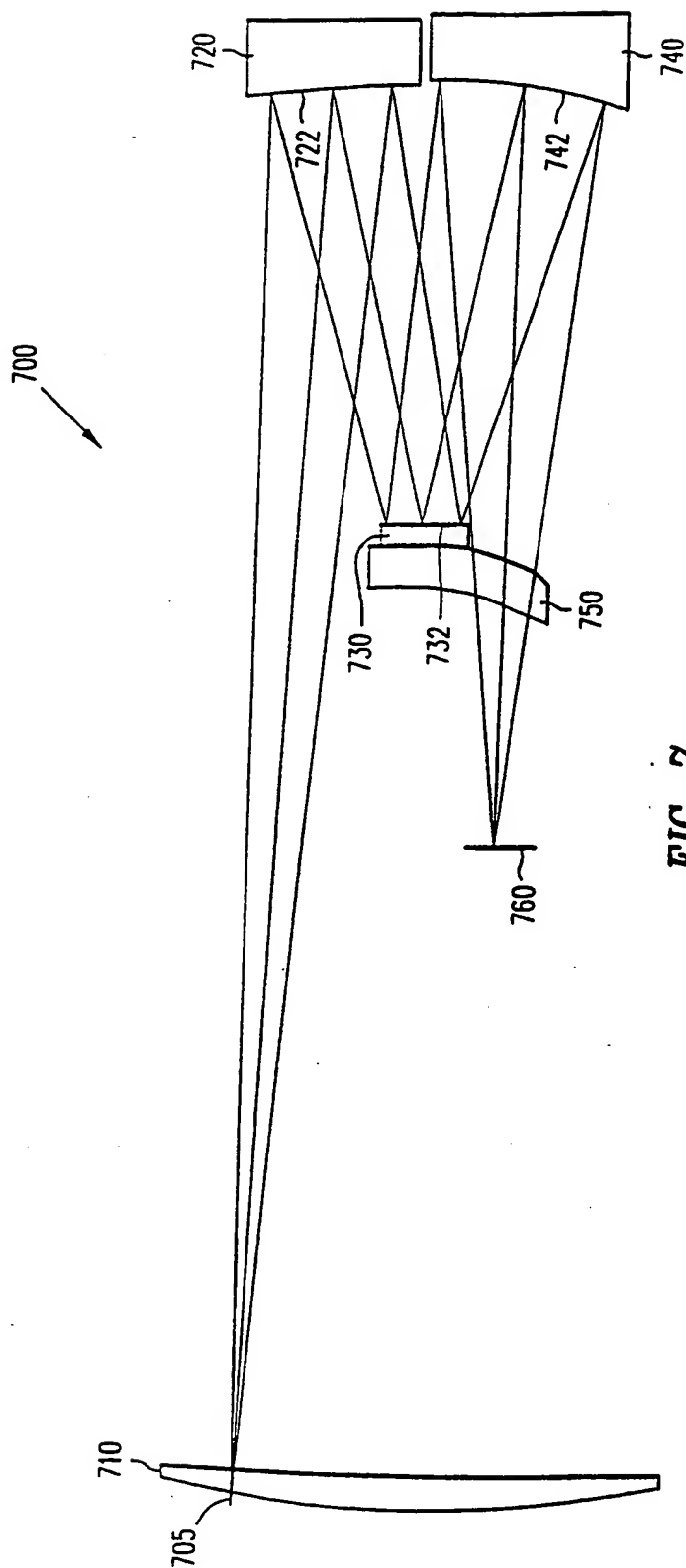


FIG. 7

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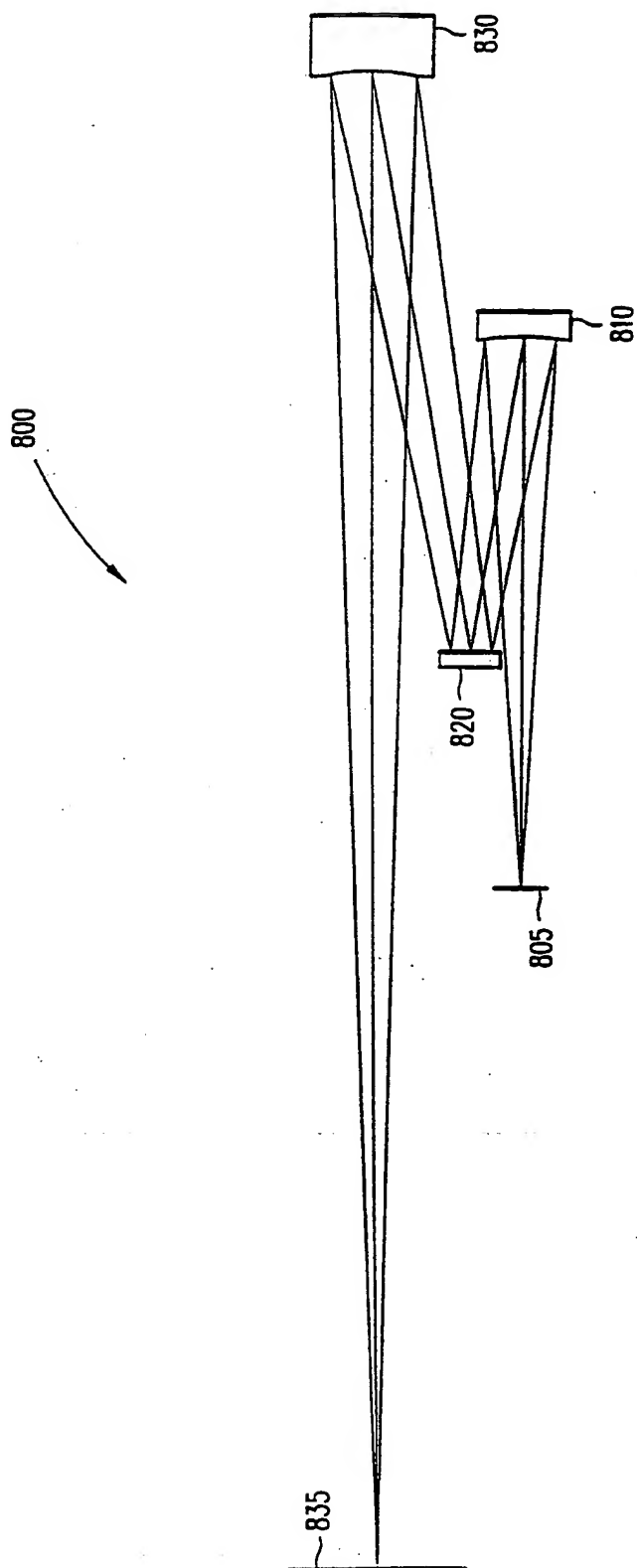


FIG. 8

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/12462

**A. CLASSIFICATION OF SUBJECT MATTER**  
IPC 6 G03F7/20

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 G03F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 796 038 A (ALLEN PAUL C ET AL) 3 January 1989 cited in the application	1, 13
Y	see column 3, line 23 - column 4, line 42	5
X	see figure 1	20
	---	
A	US 4 747 678 A (SHAFFER DAVID R ET AL) 31 May 1988	1
Y	see column 2, line 31 - line 62 see figure 2	5
	---	
	-/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

23 September 1998

Date of mailing of the international search report

02/10/1998

Name and mailing address of the ISA

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Authorized officer

Luck, W

# INTERNATIONAL SEARCH REPORT

Inte onal Application No

PCT/US 98/12462

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JEWELL T E ET AL: "REFLECTIVE SYSTEMS DESIGN STUDY FOR SOFT X-RAY PROJECTION LITHOGRAPHY" JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY: PART B, vol. 8, no. 6, 1 November 1990, pages 1519-1523, XP000169155 see chapters V and VI	5
Y	US 4 685 777 A (HIROSE RYUSHO) 11 August 1987	6
A	see column 1, line 7 - line 10 see column 2, line 42 - line 68 see figure 1	13
Y	EP 0 269 868 A (PERKIN ELMER CORP) 8 June 1988	6
A	see page 2, line 4 - line 5 see claim 1	13

# INTERNATIONAL SEARCH REPORT

information on patent family members

International Application No

PCT/US 98/12462

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			DE 3786648 T	04-11-1993
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			KR 9613806 B	10-10-1996
US 4685777	A	11-08-1987	JP 2052110 C	10-05-1996
			JP 5025170 B	12-04-1993
			JP 61156737 A	16-07-1986
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			DE 3780266 A	13-08-1992
			JP 63135912 A	08-06-1988